U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 281

INTERCOMPARISON OF ECMWF AND NMC 500 MB HEIGHT FORECASTS TO 5 DAYS

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This is an unreviewed manuscript primarily intended for
informal exchange of information among NMC staff members.

Since February of 1982 the National Meteorological Center (NMC) has been receiving, via the GTS, 500 mb height (and sea level pressure) forecasts made from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational model. The forecasts are valid from day one thru five (in 1 day increments) from the 12GMT initial observation time. They are sent on a 5° latitude-longitude grid coverning the northern hemisphere from 20°N to the pole. For NMC's convenience the data are promptly interpolated to the NMC 1 bedient grid for display and for verification and comparison between the ECMWF and NMC model forecasts. These objective verifications and intercomparisons are the subject of this essay.

Method of Verification

All verifications have been made with respect to radiosonde observations. The forecast information (500 mb heights) is biquadratically interpolated from the NMC grid points, to a selection of radiosonde observation locations. The difference (forecast minus observation) and squared differences are accumulated at each station so that monthly mean verification statistics may be compiled with ease. In addition to error statistics at individual stations, collection of stations are grouped into networks to allow for summations over space, as well as time, of the error and squared error terms.

Three such station networks are used for this report:

a) NH102: A "quasi-uniform" set of 102 regularly reporting raob stations scattered over the Northern Hemisphere (Fig. 1a);

b) NA110: All of the North American radiosondes from 20°N to 60°N and 40°W to 145°W (Fig. 1b);

c) EUR96: All of the European radiosondes from 35°N to 70°N (plus 01001) and 29°E to 10°W (Fig. 1c).

For the figures that follow the error statistics used are the mean error (bias) and standard error of the height forecasts, averaged over each of the three networks of stations and over time for either a monthly or annual period.

The period of the annual mean is from April of 1982 through March 1983, a slightly unorothodox one selected to terminate in the month prior to the ECMWF's conversion of its model from grid to spectral form.

The observations are given a quality control check prior to the calculation of the errors. The procedure makes use of a previously run analysis (NMC's) and checks that individual observations do not depart from the analysis value by too great a margin. Those that do are excluded from the subsequent verification calculations. Test have shown this to be a conservative quality control method, only removing those observations that are patently incorrect.

The NMC and ECMWF forecasts are verified against the same set of quality checked observations in precisely the same manner.

Verification Results

Figure 2 (a,b,c) shows the mean 500mb height error for the entire year as a function of forecast hour. The general tendency is for the ECMWF model to forecast heights too low and for this negative bias to grow during the period of the forecast. NMC performance is considerably more complicated, partly because of the verification of forecasts at 12-hr. intervals and the inclusion of model statistics for twice-daily runs.

In Figure 2a, NMC statistics show a generally small bias, becoming positive after 48 hrs. and increasing slightly with time. The positive bias in 3, 4 and 5 day NMC forecasts is not present in North America or European verifications (Figure 2b and c). We can only assume, therefore, that there must be relatively strong positive biases in NMC forecasts for stations in Asian or Oceanic regions (see Figure 1a).

The oscillation between positive and negative biases in 72-hr. to 120-hr. NMC forecasts over North America (Figure 2b) is probably the result of the inability of the NMC model to represent changes in temperature due to diurnal variation in solar insolation. NMC forecasts beyond 60 hrs. are made only from 00GMT analyses; thus, all 84- and 108-hrs. forecasts in the sample verify at 12GMT. These particular 500mb NMC forecasts show anomalous positive biases that are probably the result of low-level atmosphere cooling during the early morning hours that is not reflected in the model. This process is not simulated in the ECMWF model either; however, all ECMWF forecasts in the sample end at 12GMT.

Statistics over Europe (Figure 2c) show negative bias for NMC forecasts; however, this bias is less than the ECMWF bias for 36- through 96-hr. forecasts. The 12-hr. oscillation in bias is much less pronounced than over North America and, as would be expected from the time change, opposite in phase.

Figures 3 (a,b,c), 4 (a,b,c), and 5 (a,b,c) show the mean 500 mb height error for each month of the study for 1, 3, and 5 day forecasts for each area. In general NMC mean height error values suggest an annual cycle of various amplitudes (increasing with the length of the forecast).

ECMWF centre mean height errors tend to show a roughly semi-annual fluctuation, some superimposed on longer period trends. The amplitudes of these fluctuations also increase with the length of the forecast but are markedly smaller than those exhibited by NMC forecasts in NH102 and NA110. The smaller fluctuations exhibited by ECMWF forecasts in these regions suggest a better ability to incorporate seasonal heating and cooling trends, compared with NMC forecasts.

Of special interest are the mean 500 mb height error graphs for area NH102 (Fig. 2a, 3a, 4a & 5a). Figure 2a shows that the annual mean error for NMC forecasts is small regardless of the length of the forecast, while ECMWF forecasts show increasingly negative values (heights too low), making -17.5m at 120 hours. For individual months NMC mean error values are either quite high or low and tend to cancel in the annual means. ECMWF monthly errors, although variable from month to month, are less so than NMC - ECMWF shows a more consistent bias which may be easier for a user to contend with than NMC's rather more variable bias.

Fig. 6 (a,b,c) shows the mean standard error for 500 mb. height for the entire one-year period, as a function of forecast hour. As can be seen, the ECMWF model consistently outperforms the NMC model. In addition, the lines diverge in areas NH102 and EUR96, indicating a slowly increasing advantage for the ECMWF model as forecast time increases. In area NH110, the lines are nearly parallel beyond 48 hours.

Fig. 7 (a,b,c) show the monthly values of mean standard error for 500 mb height forecasts (24, 72 and 120 hours). The ECMWF model's superiority over the NMC model is quite consistent. The various pairs of curves are fairly parallel, especially at 24 hours, and there are few points where the NMC model is better than the ECMWF model. Both models exhibit seasonal cycles (maximum error in summer, minimum in winter); however, changes in the model's performance with respect to each other seem to occur in a rather random fashion.

Mean Time Advantage of ECMWF Over NMC

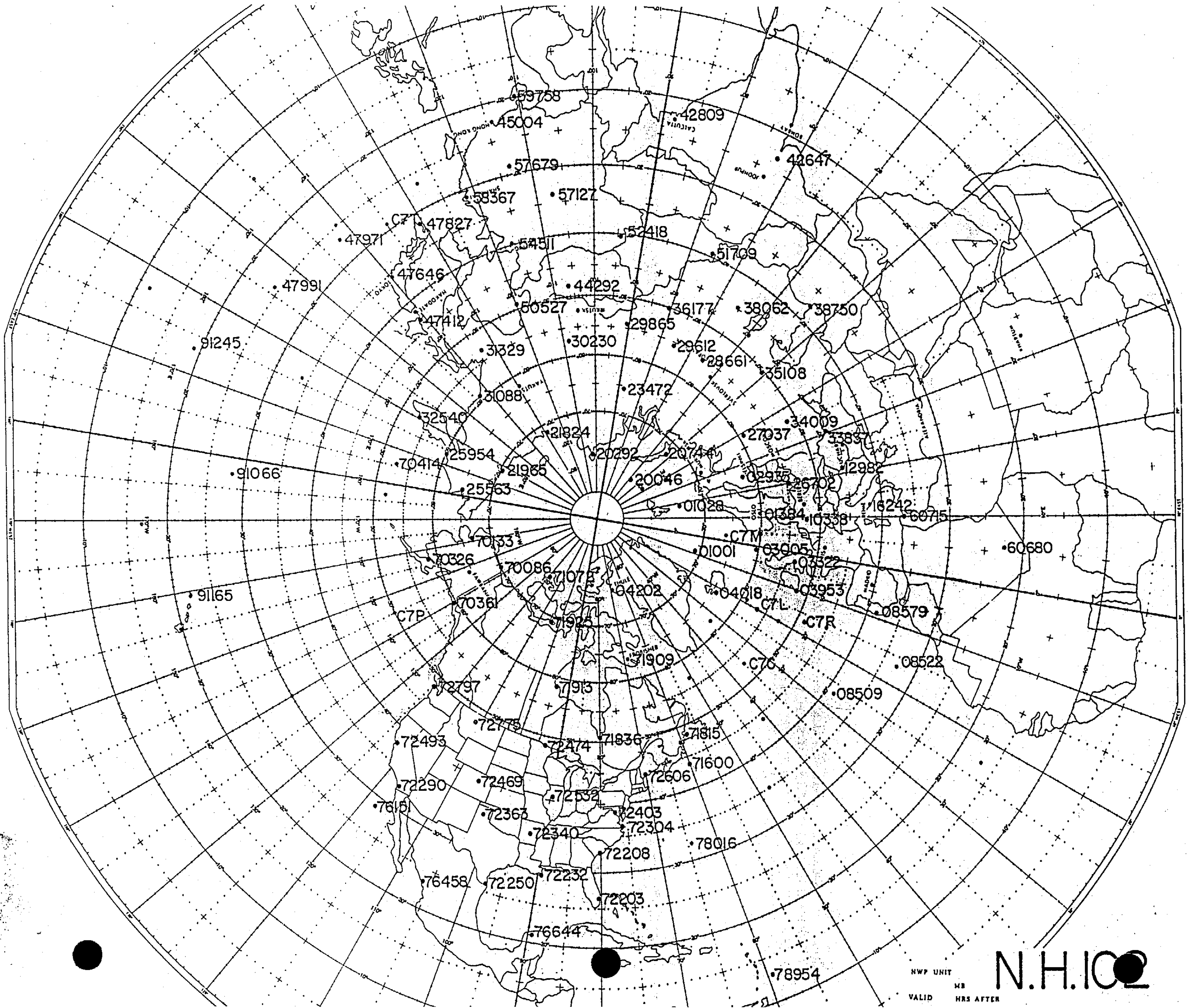
Another informative way of looking at the relative merits of the forecasts from the two centers is in terms of how fast the errors grow with length of forecast. In particular the relative error growth can be couched in terms of the time advantage one model may have over another. This can be defined by reference to the annual mean standard error vs. forecast time charts presented earlier. The "time advantage" is the horizontal separation distance between any pair of points on the two error curves. It represents of course, the number of hours (or days) that one model is ahead ("better") than the other; for example if the 4 hour forecast error of the ECMWF model is the same as that of the NMC model at 14 hours, one asserts that ECMWF model is 10 hours "better".

Rather than extract this information from the annual mean error vs. forecast time graphs we have turned to monthly mean graphs (not shown). This enables us to indicate how much variability there is in the time advantage over the course of the April 1982 - March 1983 year. The calculation simply involves the tabulation of the time separation of the ECMWF and NMC forecast errors for the points 1 thru 5 days of the ECMWF forecast, followed by calculation of the mean and standard deviation. The results are plotted in Fig. 8 (a,b,c) for the three verification areas. (We have assumed a linear variation of error in the NMC error curves between the 12 or 24 hourly verification times.)

In the Northern Hemisphere sample, (Figure 8a), ECMWF forecasts based upon data from April 1982 through March 1983 are more accurate than NMC forecasts by about 5 hrs. at one day, 10 hrs. at 3 days and 15 hrs. at 5 days. Corresponding figures over Europe (Figure 8c) are about 8 hrs., 14 hrs. and 19 hrs. In both of these samples, the change of time advantage is quite linear, with forecast advantage increasing at a rate of about 25 to 3 hrs. per forecast day. Over North America (Figure 8b) the advantage is about 6 to 7 hrs. at one day but the rate of increase is only about 1.5 hrs. per day.

Although the points in Figures 8 (a,b,c) appears to be linearly related, it is obvious that that is partly an artifact of the restriction of comparison to forecasts out to 5 days. If we assume that neither model has skill beyond day n (where n is probably in the range from about 7 to 9), then the advantage of one model over the other should disappear at day n. Thus, the advantage may grow in an apparently linear fashion for some time, reaching a maximum prior to day n and then fall to 0.

Because of the clear advantage of the ECMWF forecast as early as day 1, it is difficult to assume that the superiority of the 500mb forecasts is due largely to more sophisticated physics. This may undoubtedly be a factor, especially in the longer time ranges, however, the later data cut-off (9 hrs. compared to less than 4 hrs.), differences in the analysis system and higher resolution in the forecast model all must play a role. It will be interesting to see how these statistics change as we increase the resolution of the NMC forecast model, improve the NMC analysis scheme and then gradually introduce more sophisticated radiation, boundary layers and precipitation physics.



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45004
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42647
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27037
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21965
20046
02935
26702
25563
01028
16242
01384
10338
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C7M
70133
01001
03005
60680
70326
03522
70086
71078
04202
04018
03953
91165
70361
C7L
08579
C7P
C7R
71925
71909
C7C
08522
72797
71913
08509
72775
71815
72493
72474
71836
71600
72606
72469
72290
72532
76151
72363
72403
72304
72340
78016
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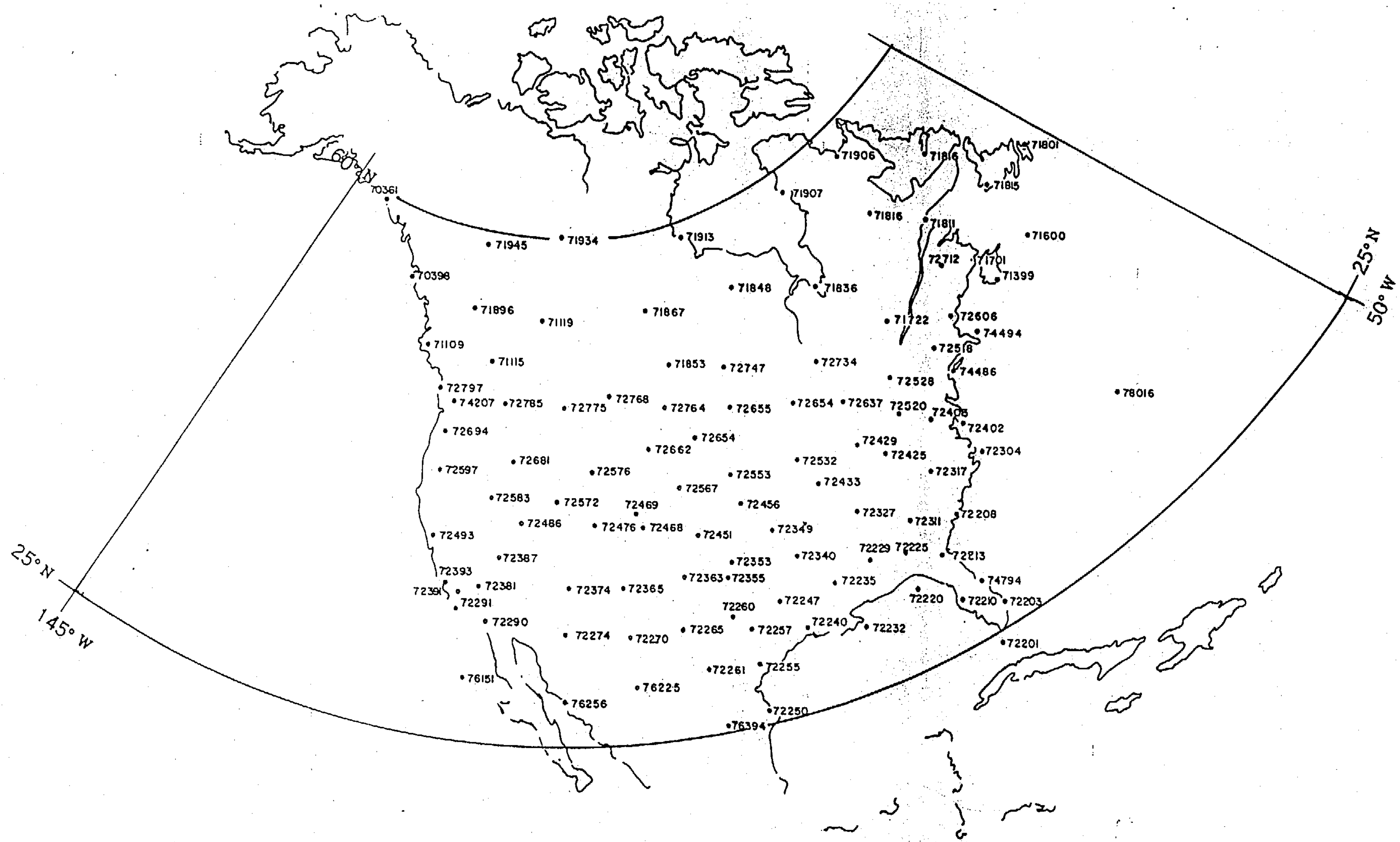
76458
72250
72232
72203
76644
78954
NWP UNIT
MB
VALID
HRS AFTER
N.H.102

Figure 1a


60°N
25°N
145° W
25°N
50° W
70361
71945
71934
71913
71906
71816
71801
71907
71815
71816
71811
71600
72712
71701
71399
70398
71848
71836
71896
71119
71867
71722
72606
74494
71109
72518
71115
71853
72747
72734
74486
72528
72797
74207
72785
72775
72768
72764
72655
72654
72637
72520
72405
78016
72402
72694
72654
72662
72429
72425
72304
72597
72681
72576
72553
72532
72317
72567
72433
72583
72572
72469
72456
72327
72208
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72311
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72381
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72210
72203
72291
72260
72247
72290
72240
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72265
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72201
72261
72255
76151
76225
76256
72250
76394

Figure 1b

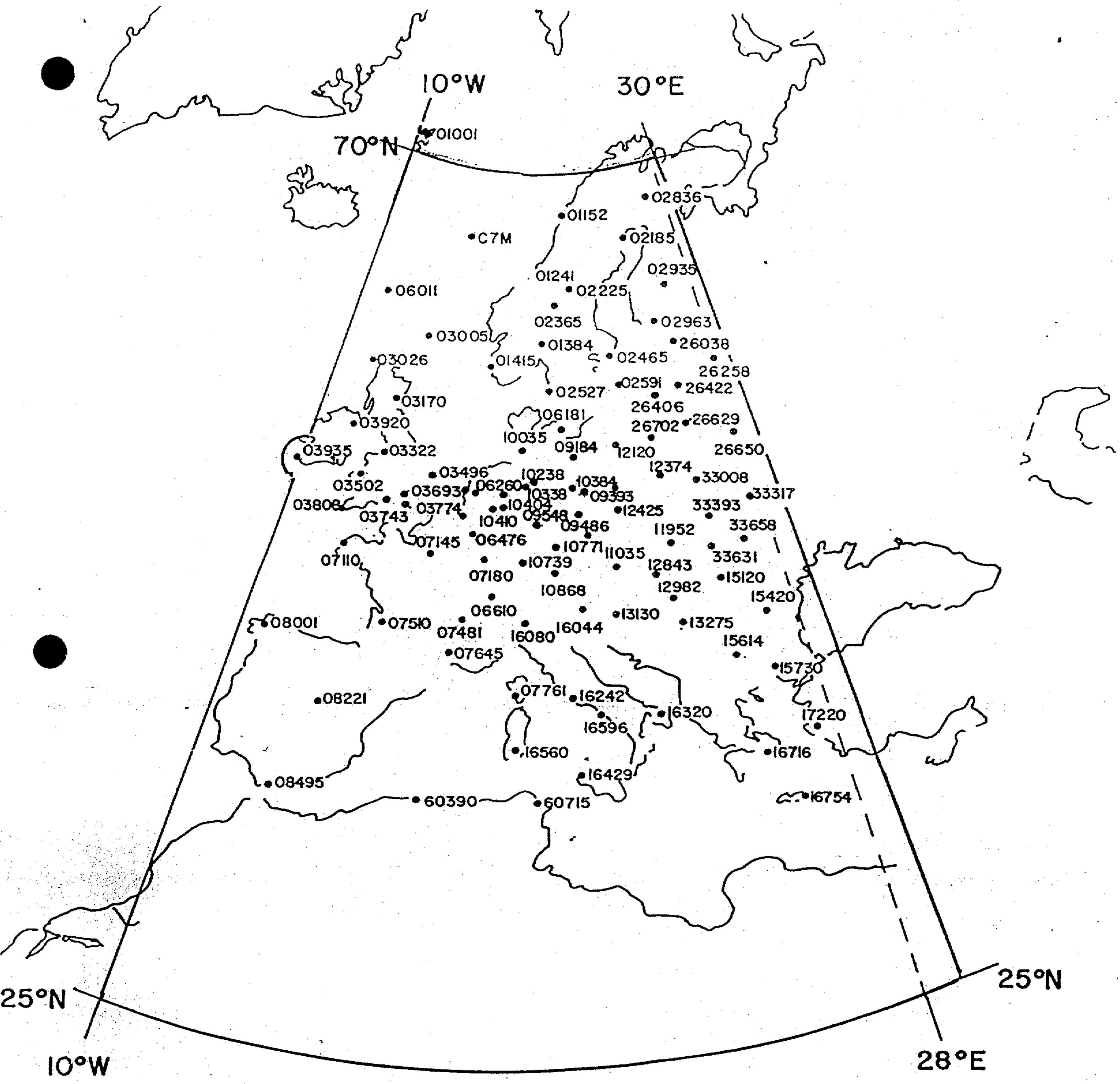
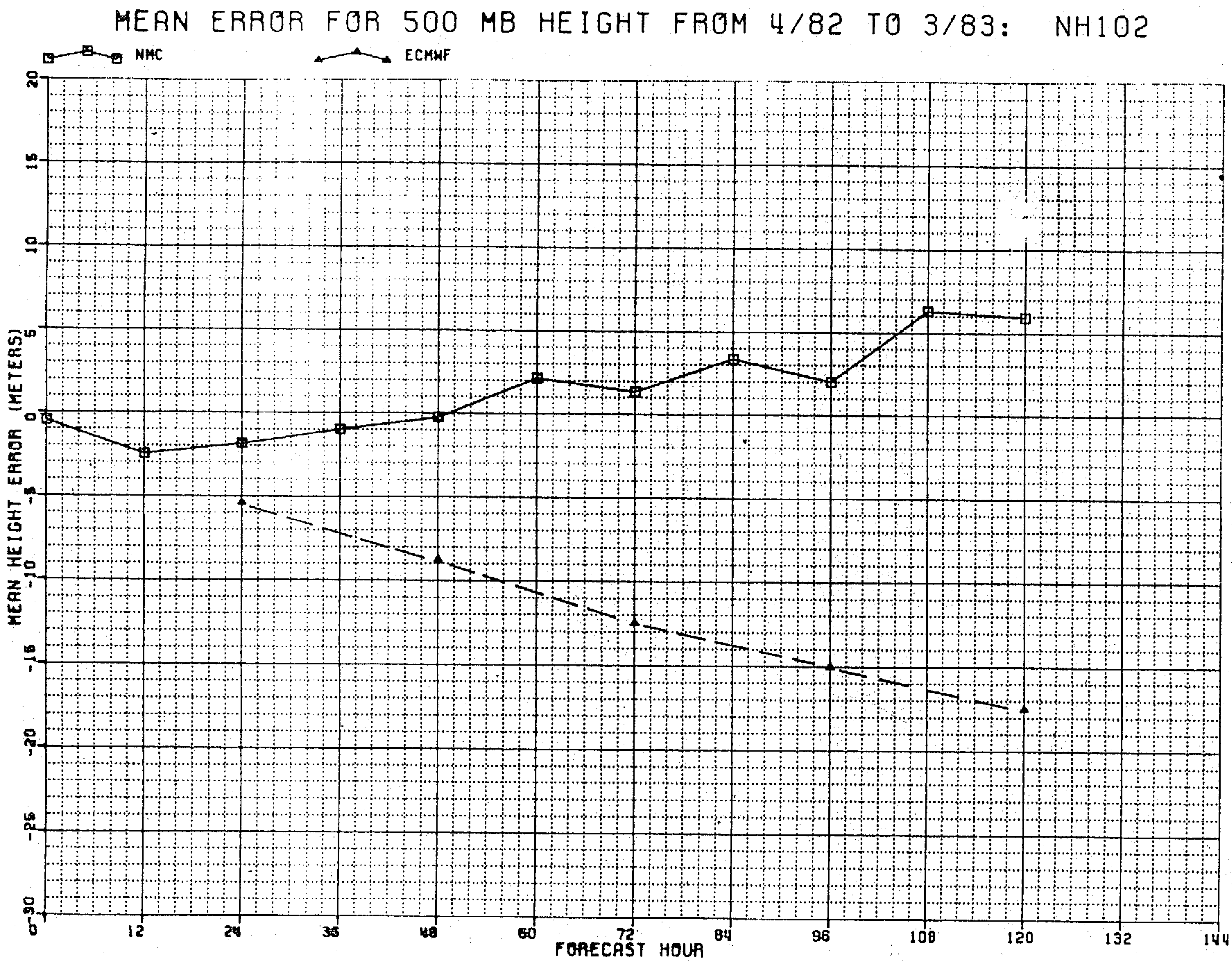

10°W
30°E
70°N
01001
02836
01152
C7M
02185
01241
02935
06011
02225
02365
02963
03005
01384
26038
03026
01415
02465
26258
02591
26422
03170
02527
26406
03920
06181
26702
26629
10035
09184
12120
26650
03935
03322
03496
10238
10384
12374
33008
03502
03693
06260
10338
09393
33317
03808
03774
10404
12425
33393
03743
09548
10410
09486
11952
33658
07145
06476
10771
11035
33631
07110
10739
12843
15120
07180
12982
10868
15420
06610
13130
08001
07510
07481
16080
16044
13275
15614
07645
15730
07761
16242
08221
16320
17220
16596
16716
16560
16429
08495
60390
60715
16754
25°N
25°N
10°W
28°E

Figure 1c



MEAN ERROR FOR 500 MB HEIGHT FROM 4/82 TO 3/83: NH102
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
0
12
24
36
48
60
72
84
96
108
120
132
144
FORECAST HOUR

Figure 2a

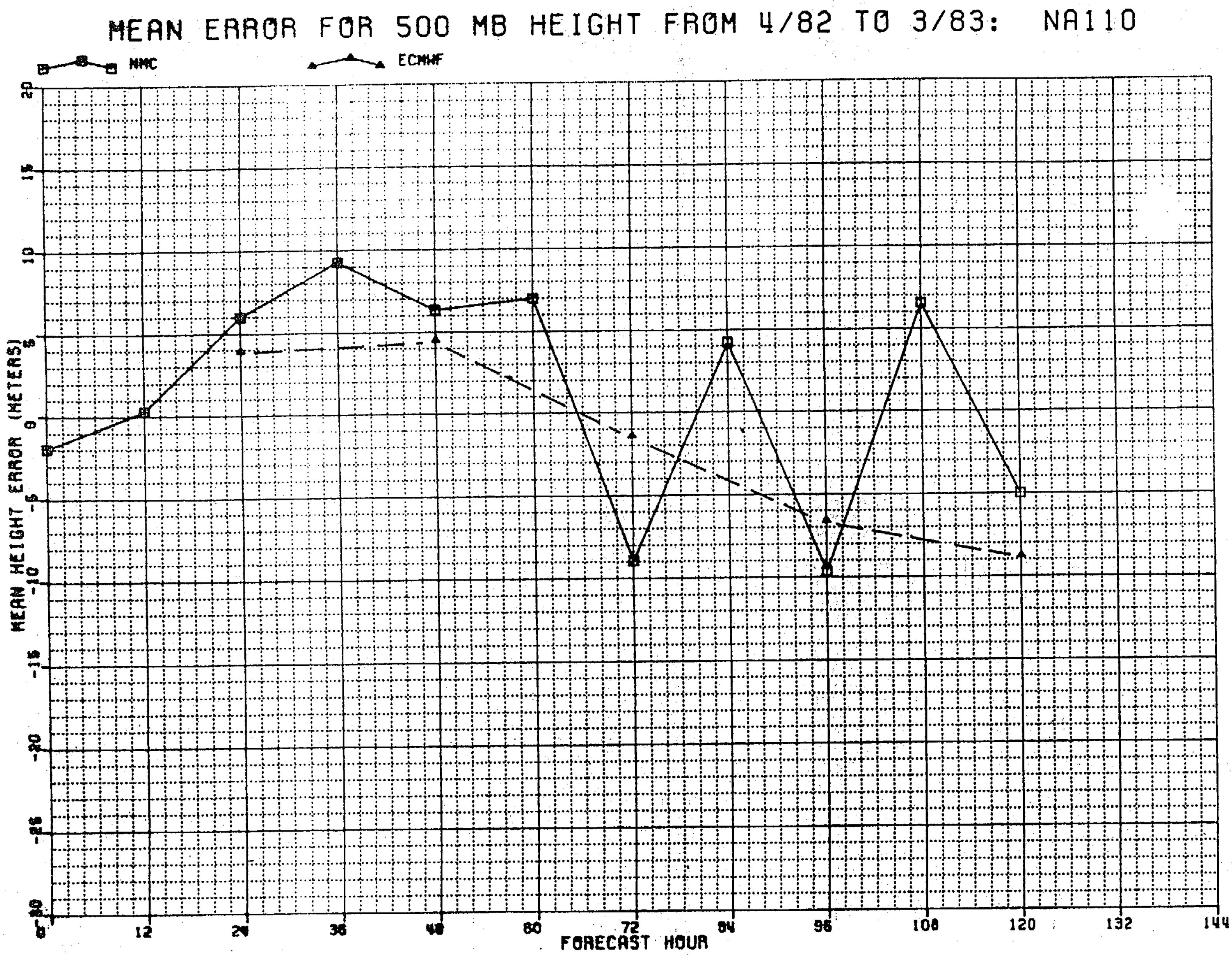
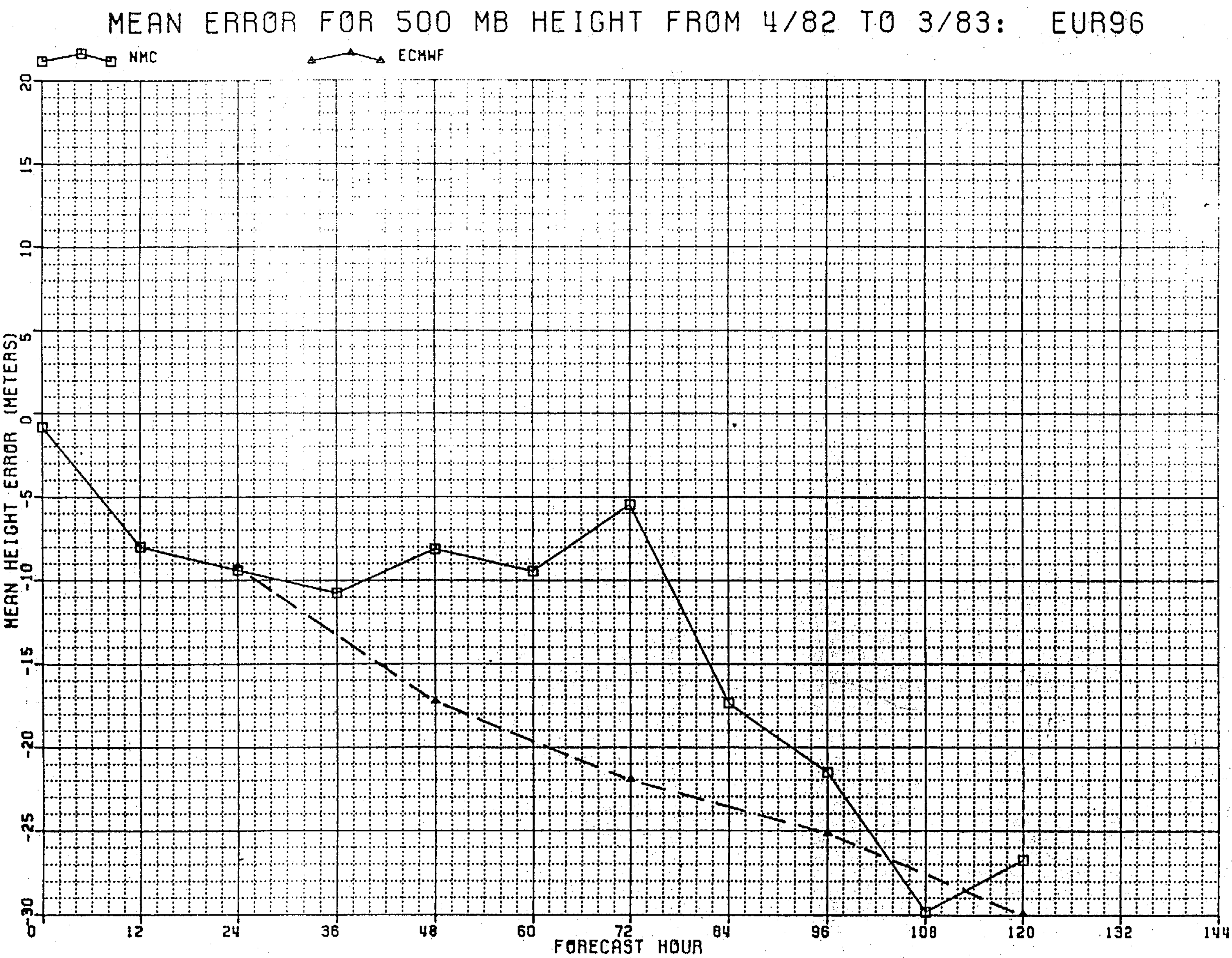
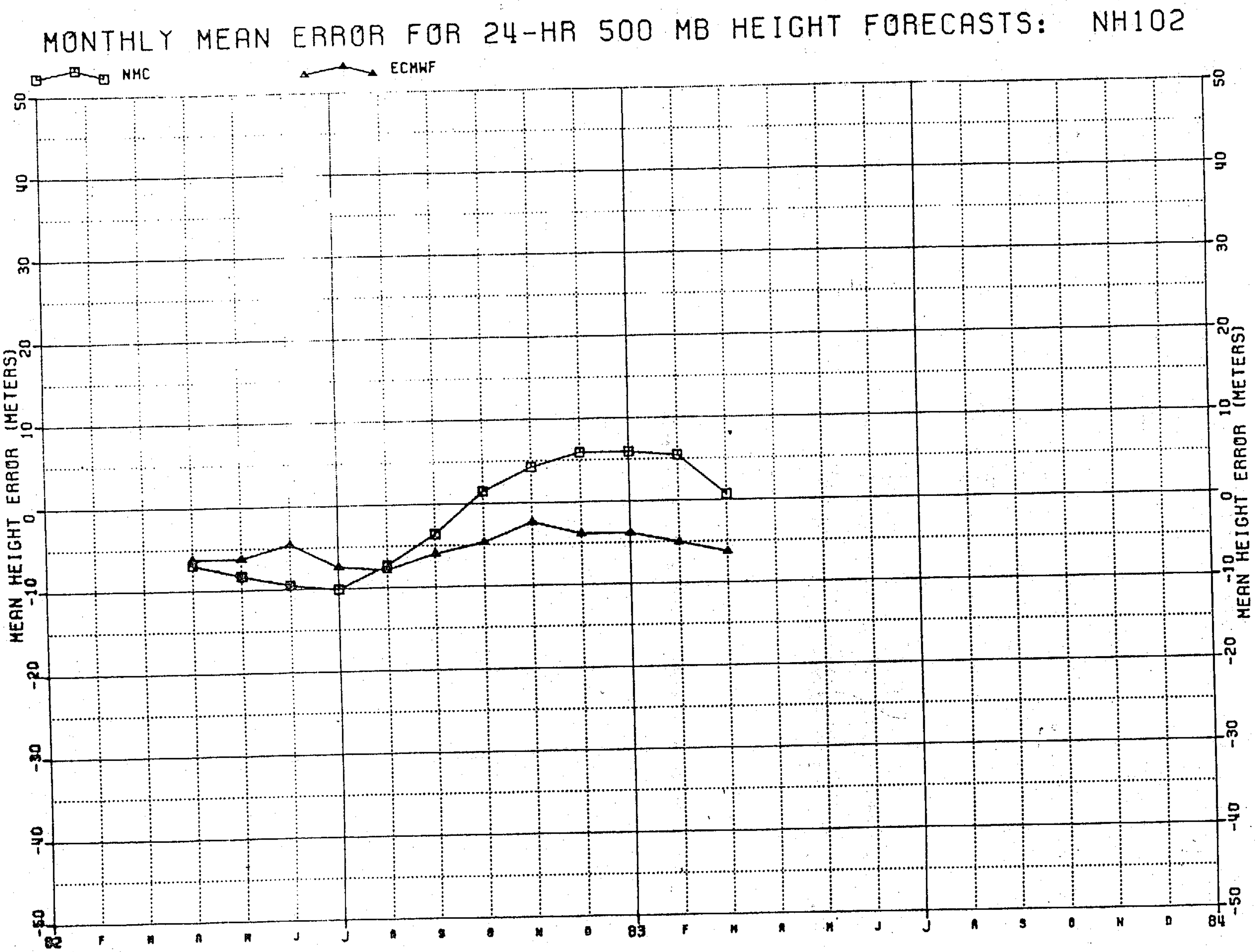

MEAN ERROR FOR 500 MB HEIGHT FROM 4/82 TO 3/83: NA110
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
0
12
24
36
48
60
72
84
96
108
120
132
144
FORECAST HOUR

Figure 2b



MEAN ERROR FOR 500 MB HEIGHT FROM 4/82 TO 3/83: EUR96
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
0
12
24
36
48
60
72
84
96
108
120
132
144
FORECAST HOUR

Figure 2c



MONTHLY MEAN ERROR FOR 24-HR 500 MB HEIGHT FORECASTS: NH102
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
MEAN HEIGHT ERROR (METERS)
50
40
30
20
10
0
-10
-20
-30
-40
-50
82
F
M
A
M
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J
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N
D
83
F
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A
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J
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A
S
O
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D
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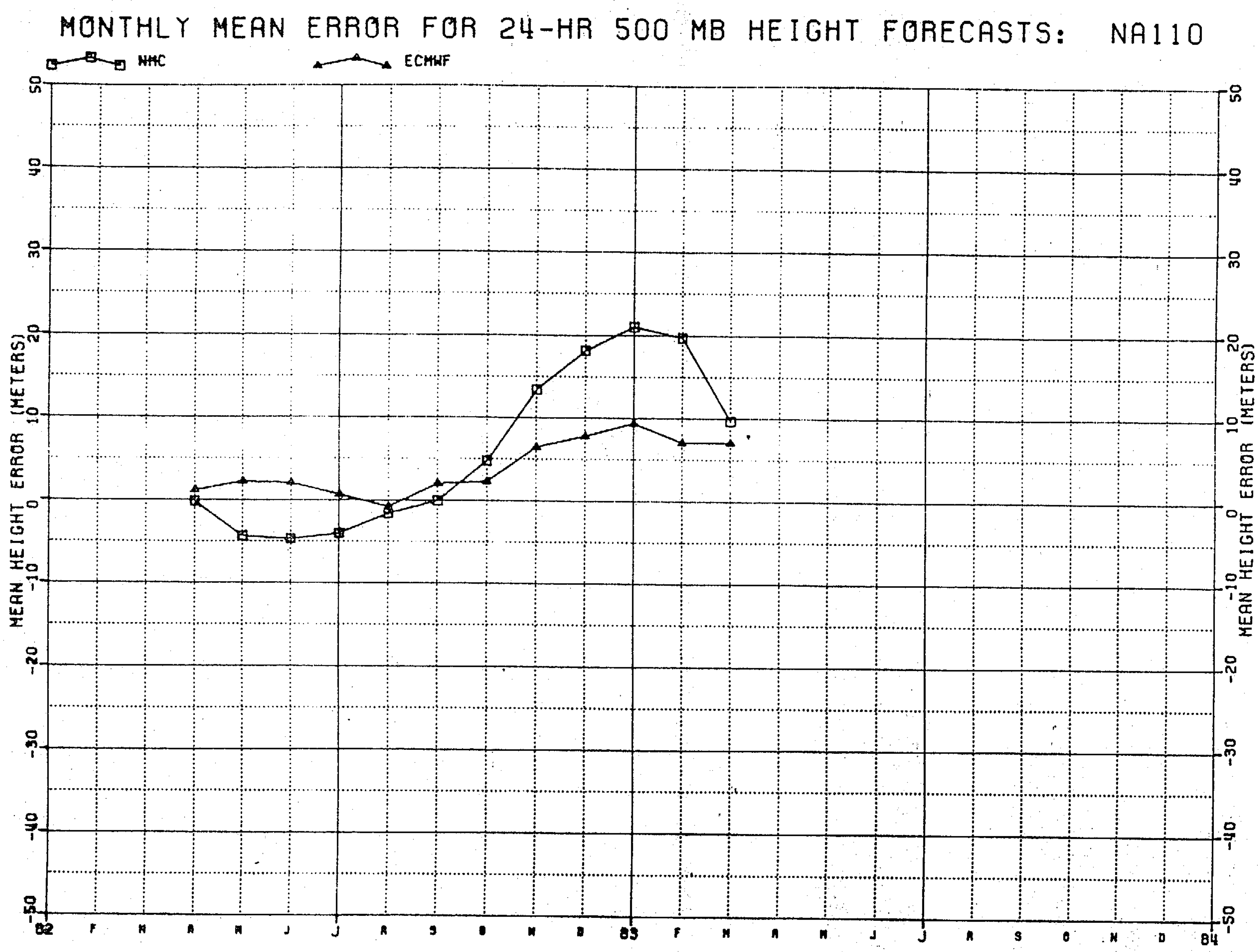
Figure 3a



MONTHLY MEAN ERROR FOR 24-HR 500 MB HEIGHT FORECASTS: NA110
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
50
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-10
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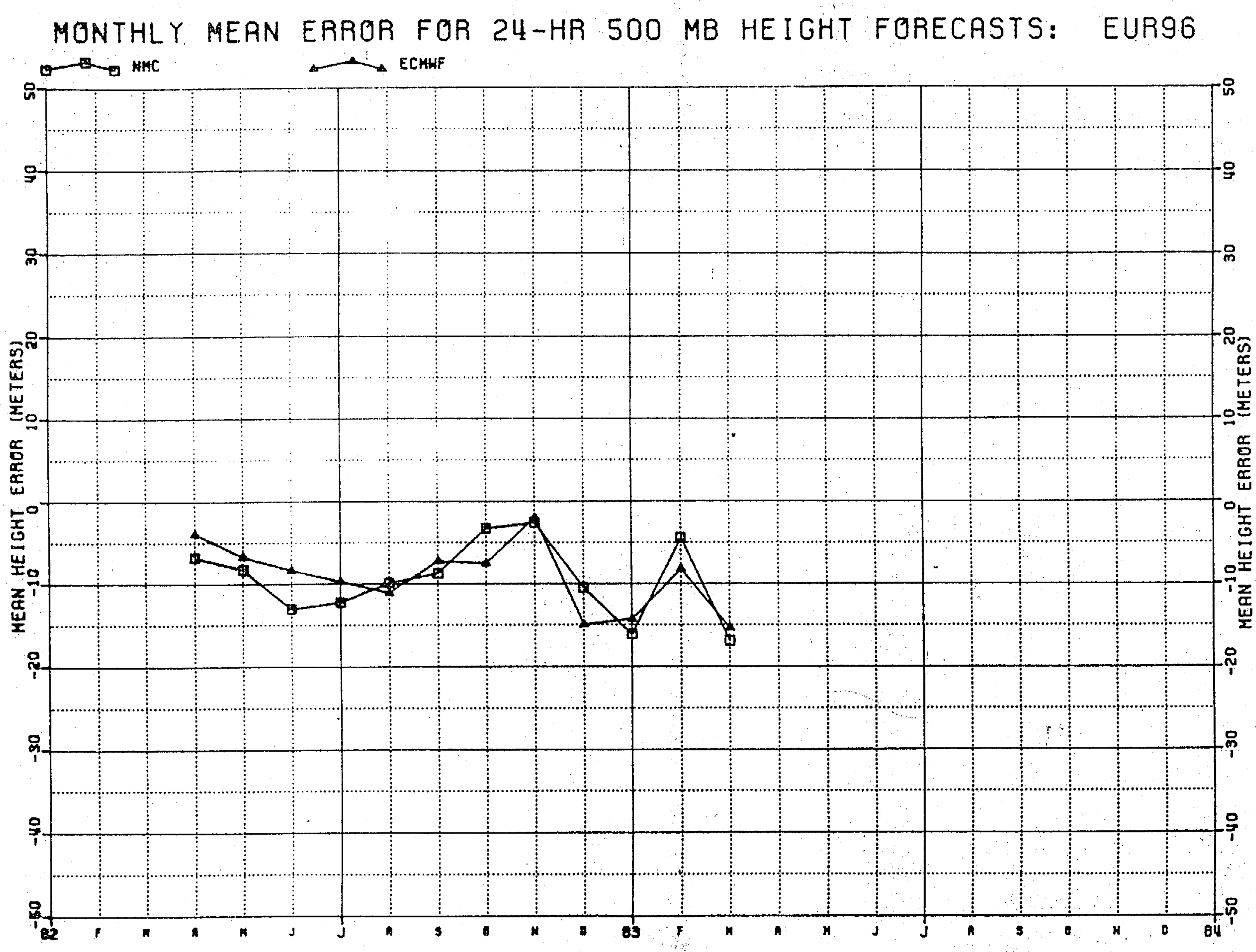
-30
-40
-50
82 F M A M J J A S O N D 83 F M A M J J A S O N D 84

Figure 3b


MONTHLY MEAN ERROR FOR 24-HR 500 MB HEIGHT FORECASTS: EUR96
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ECMWF
MEAN HEIGHT ERROR (METERS)
50
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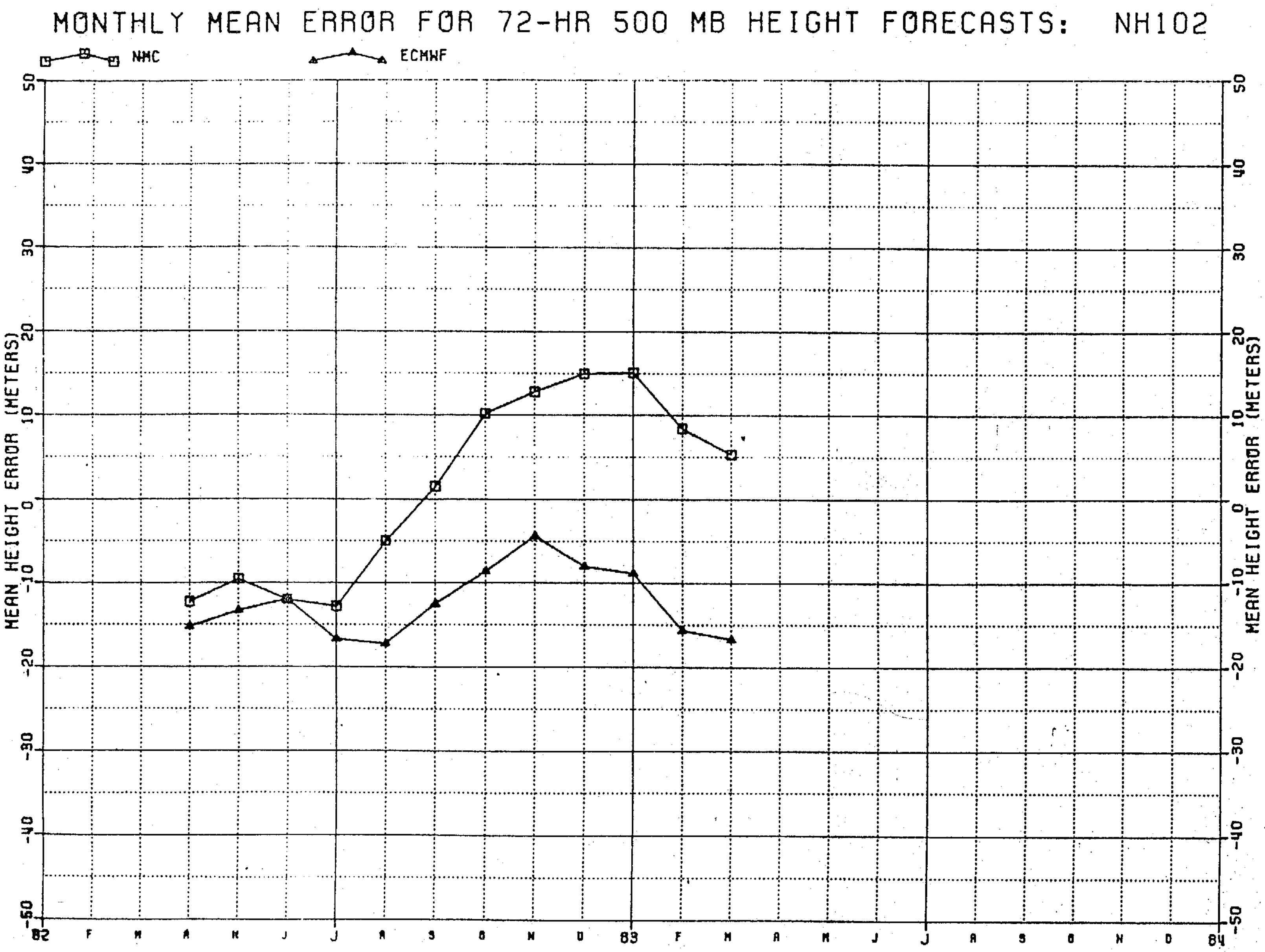
-50
82 F M A M J J A S O N D 83 F M A M J J A S O N D 84

Figure 3c


MONTHLY MEAN ERROR FOR 72-HR 500 MB HEIGHT FORECASTS: NH102
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
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-10
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82
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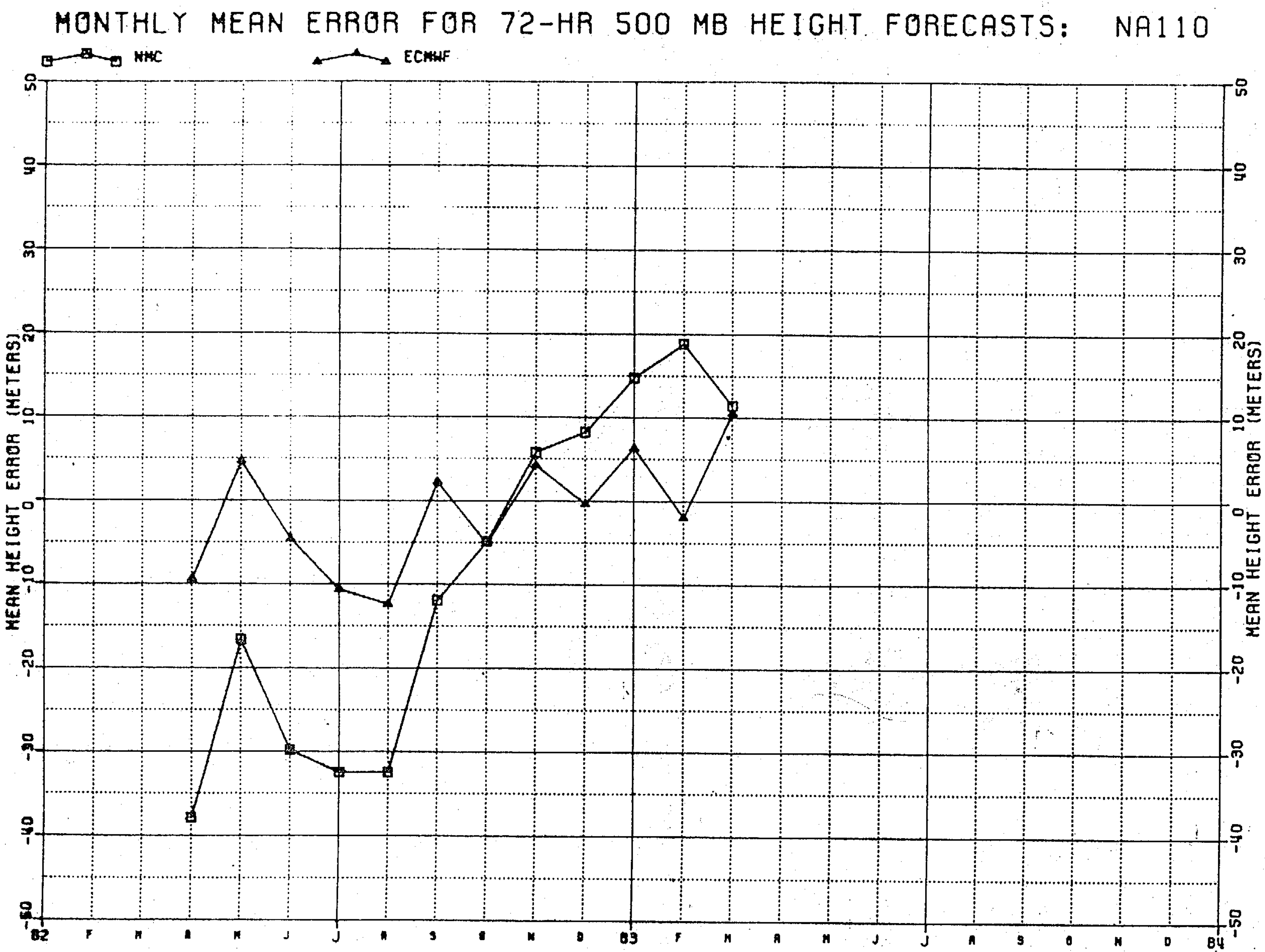
84

Figure 4a


MONTHLY MEAN ERROR FOR 72-HR 500 MB HEIGHT FORECASTS: NA110
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
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82
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Figure 4b

MONTHLY MEAN ERROR FOR 72-HR 500 MB HEIGHT FORECASTS: EUR96

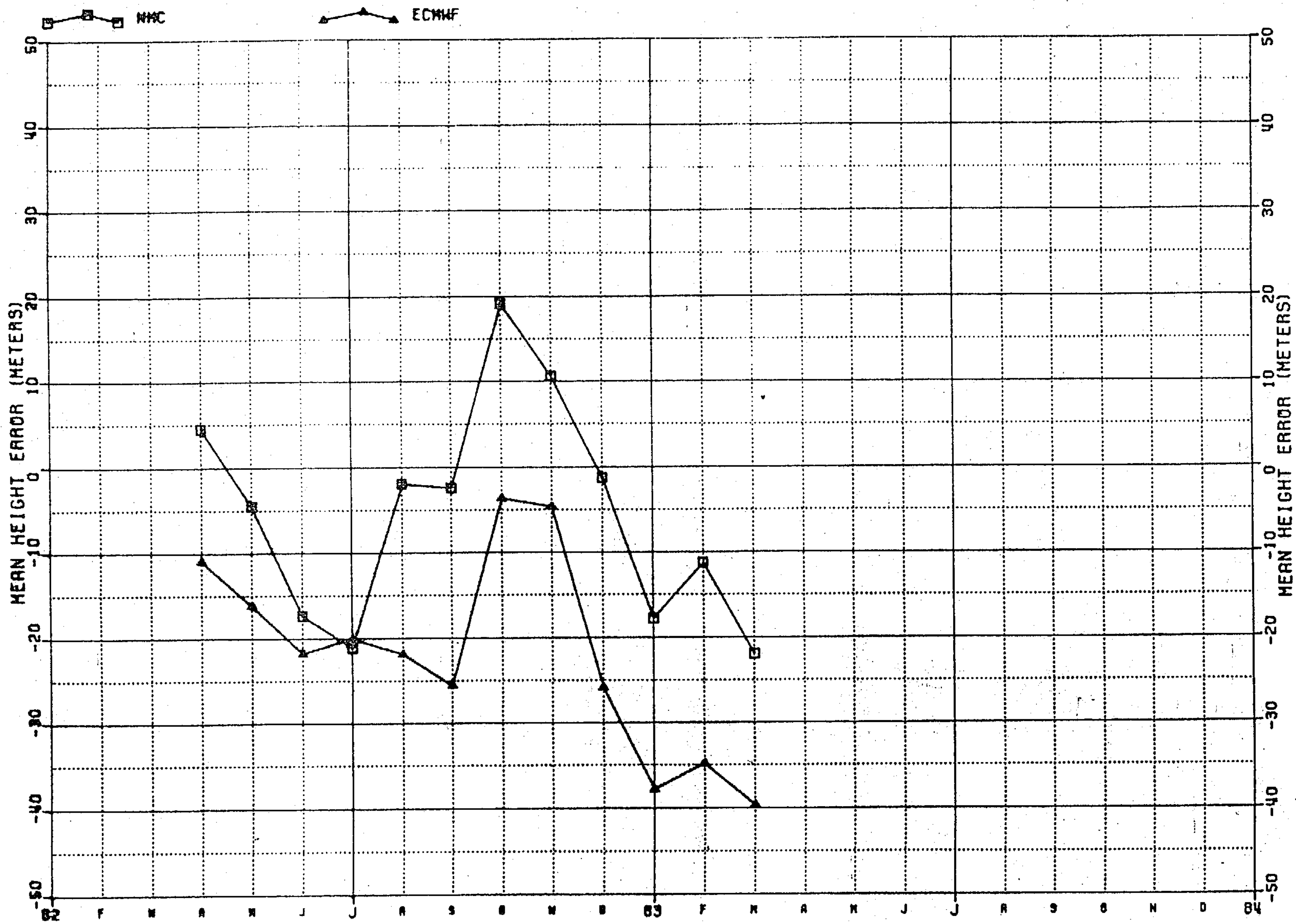
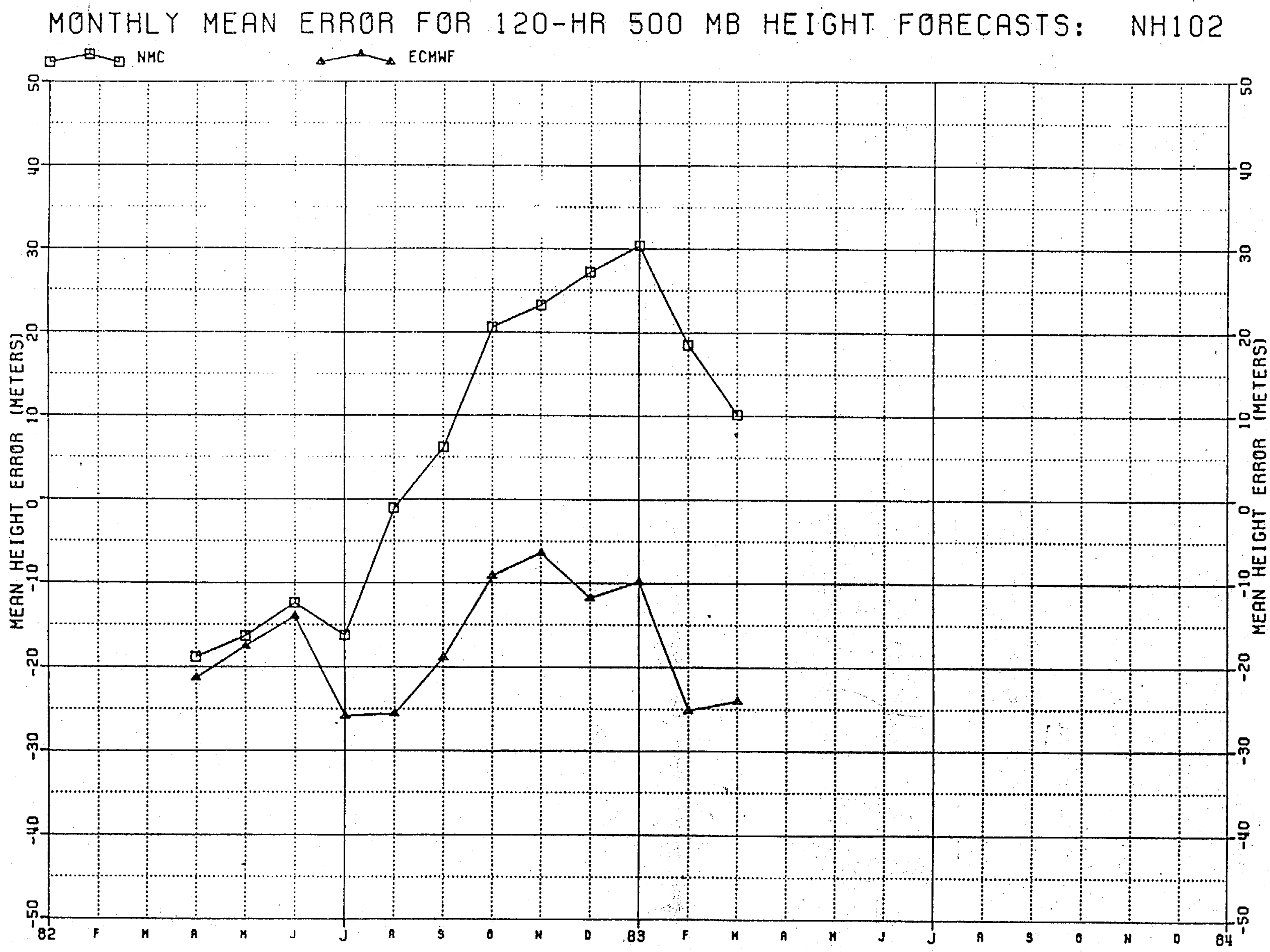


Figure 4c


MONTHLY MEAN ERROR FOR 120-HR 500 MB HEIGHT FORECASTS: NH102
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
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40
30
20
10
0
-10
-20
-30
-40
-50
82
F
M
A
M
J
J
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83
F
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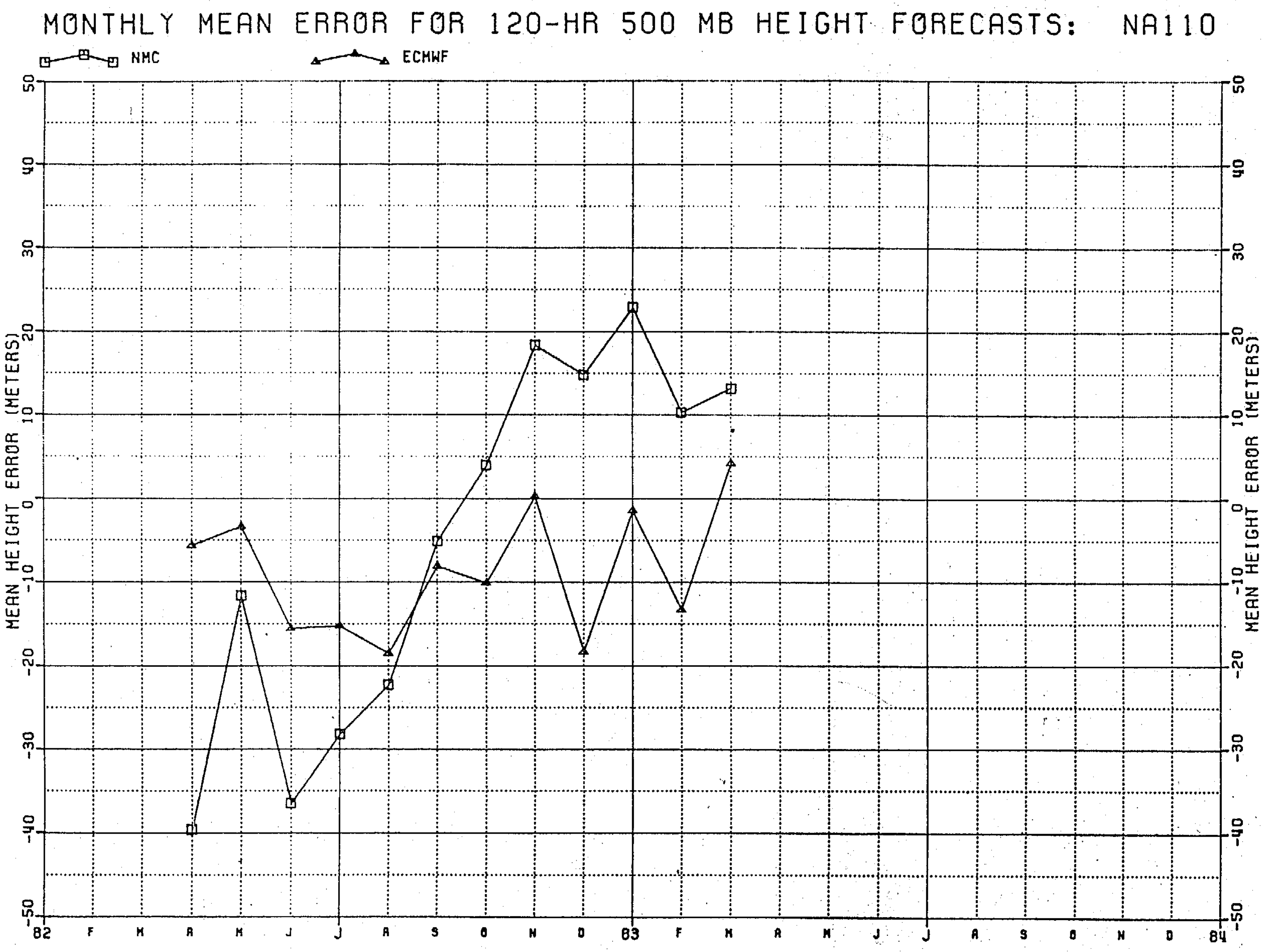
O
N
D
84

Figure 5a


MONTHLY MEAN ERROR FOR 120-HR 500 MB HEIGHT FORECASTS: NA110
NMC
ECMWF
MEAN HEIGHT ERROR (METERS)
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40
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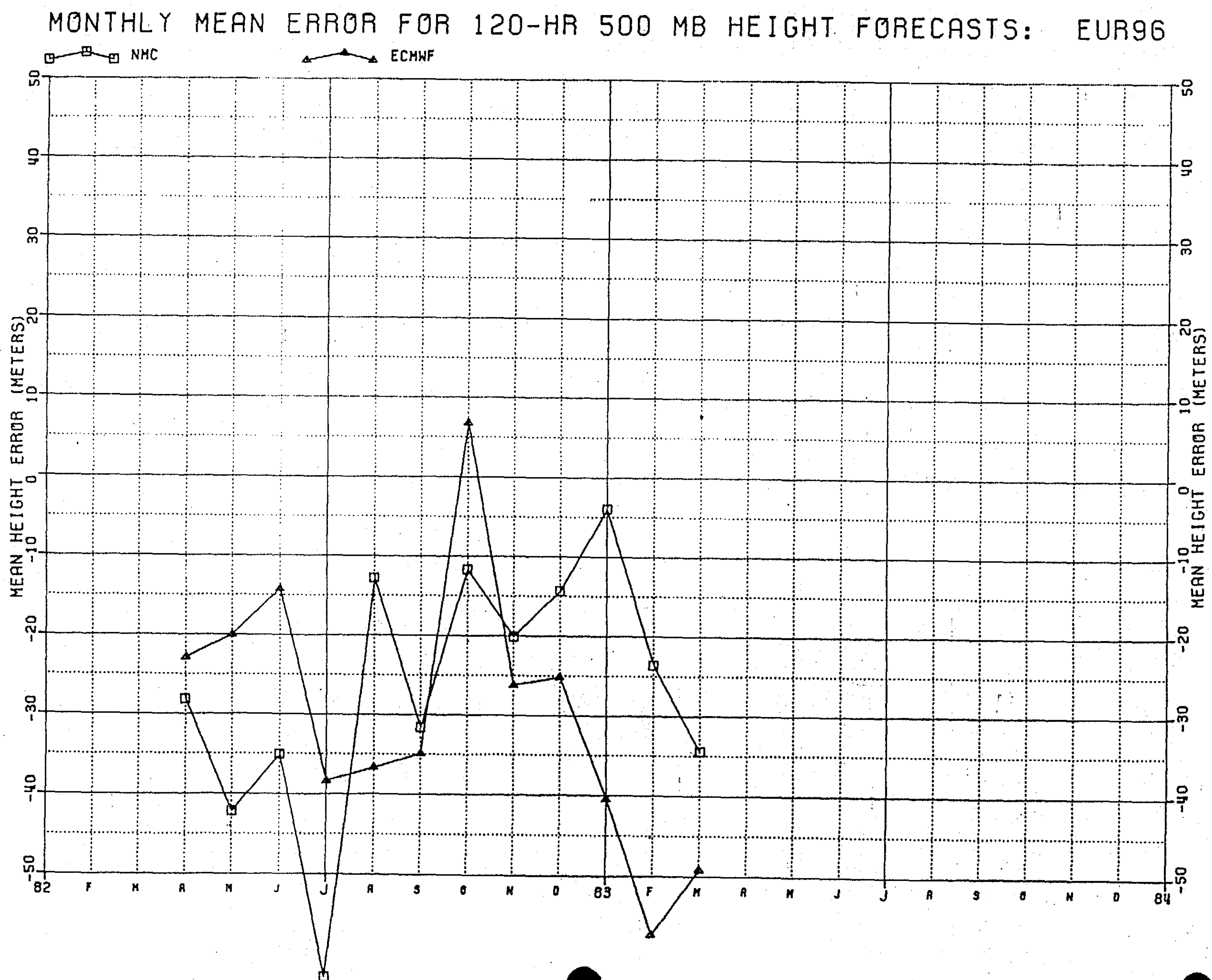
82 F M A M J J A S O N D 83 F M A M J J A S O N D 84

Figure 5b


MONTHLY MEAN ERROR FOR 120-HR 500 MB HEIGHT FORECASTS: EUR96
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ECMWF
MEAN HEIGHT ERROR (METERS)
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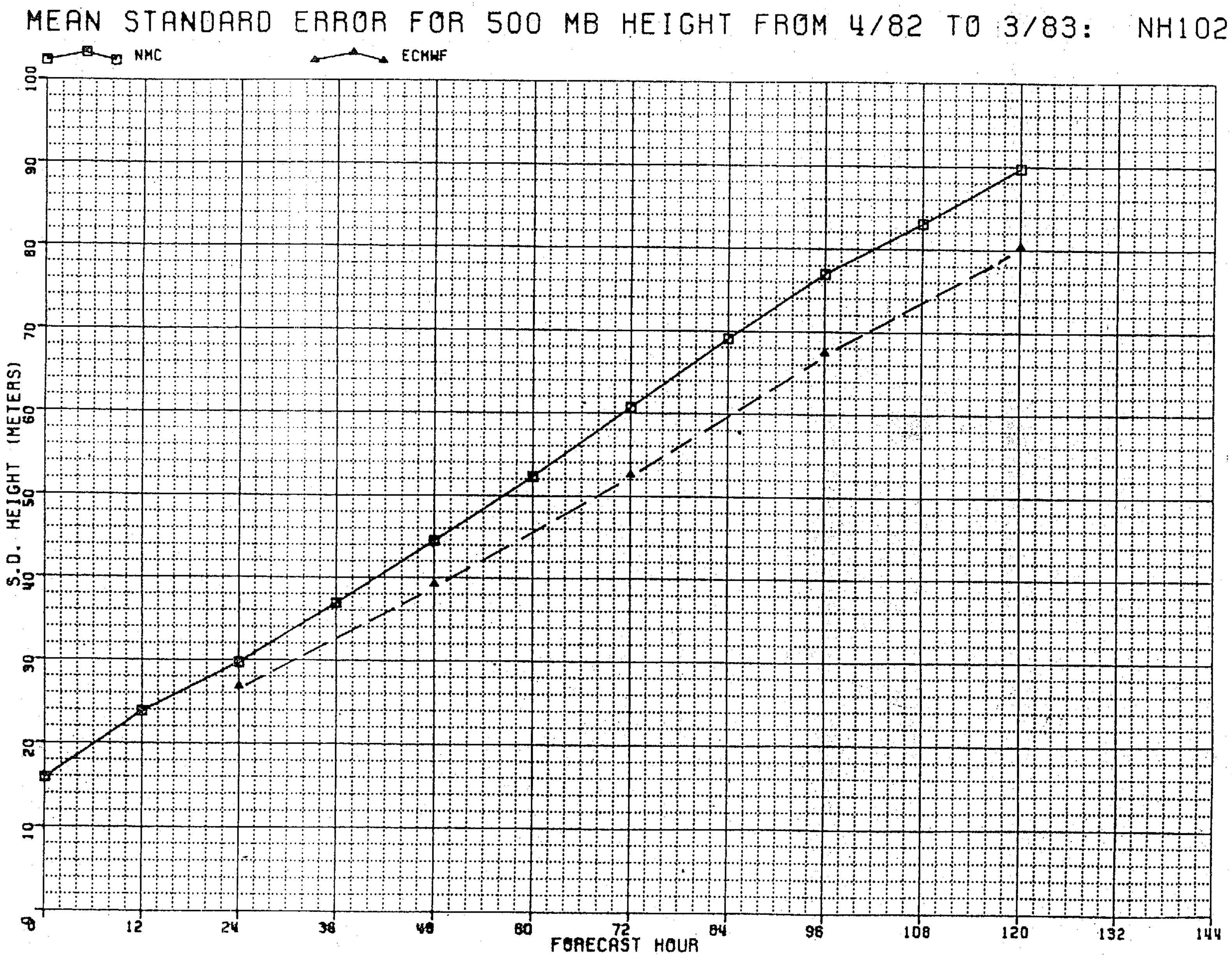
-40
-50
82 F M A M J J A S O N D 83 F M A M J J A S O N D 84

Figure 5c


MEAN STANDARD ERROR FOR 500 MB HEIGHT FROM 4/82 TO 3/83: NH102
NMC
ECMWF
S.D. HEIGHT (METERS)
FORECAST HOUR
0
12
24
36
48
60
72
84
96
108
120
132
144
10
20
30
40
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60
70
80
90
100

Figure 6a

MEAN STANDARD ERROR FOR 500 MB HEIGHT FROM 4/82 TO 3/83: NA110

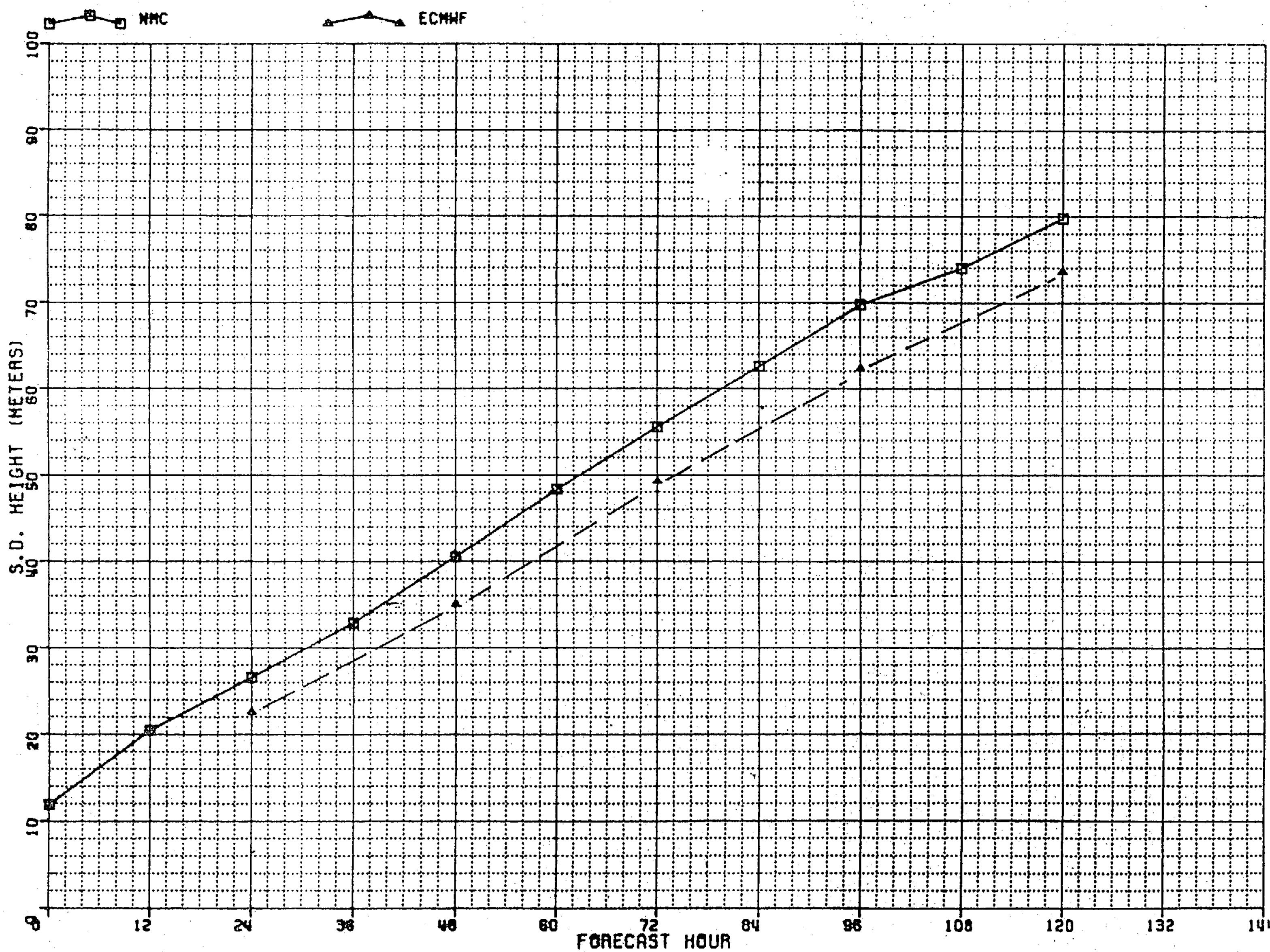
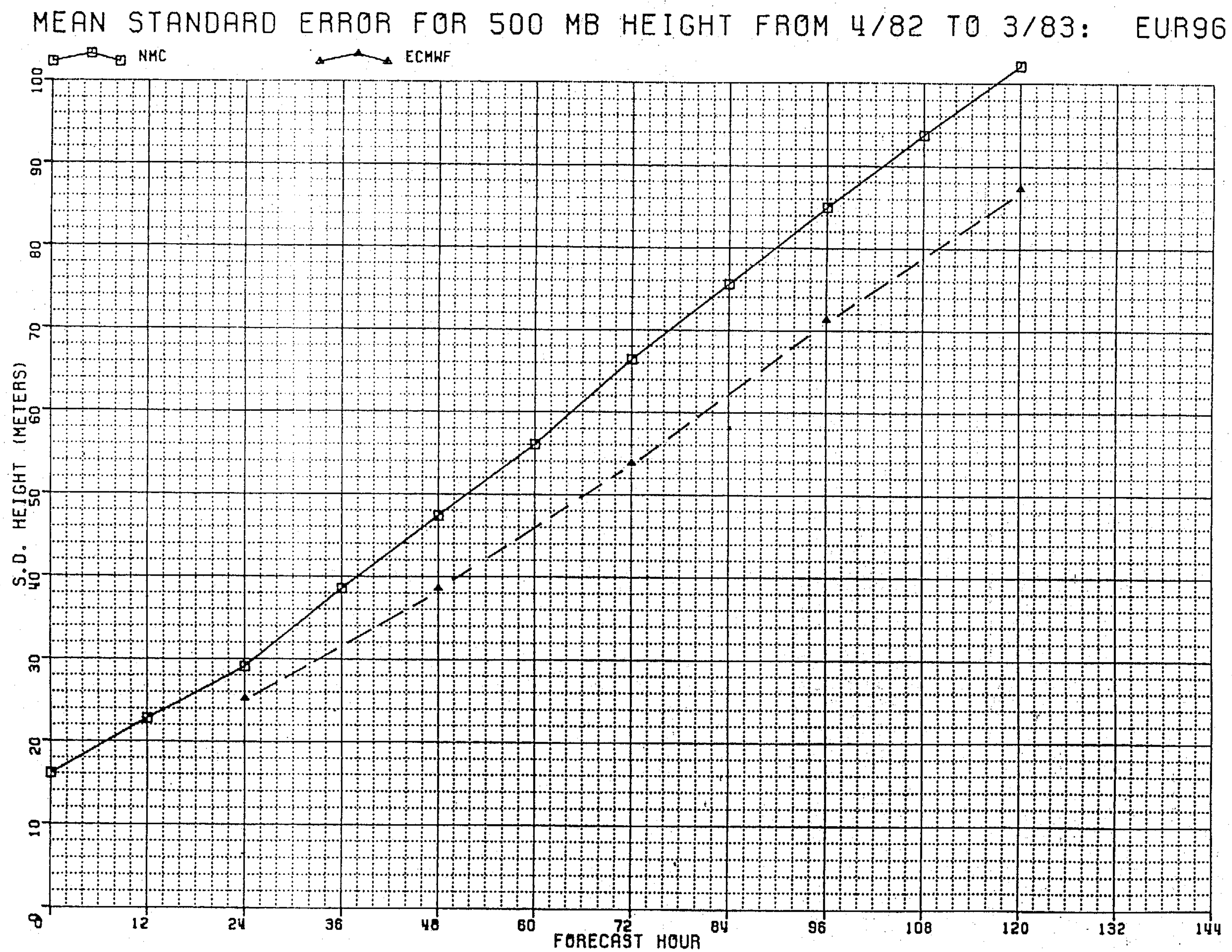


Figure 6b


MEAN STANDARD ERROR FOR 500 MB HEIGHT FROM 4/82 TO 3/83: EUR96
NMC
ECMWF
S.D. HEIGHT (METERS)
0
10
20
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40
50
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70
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100
0
12
24
36
48
60
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84
96
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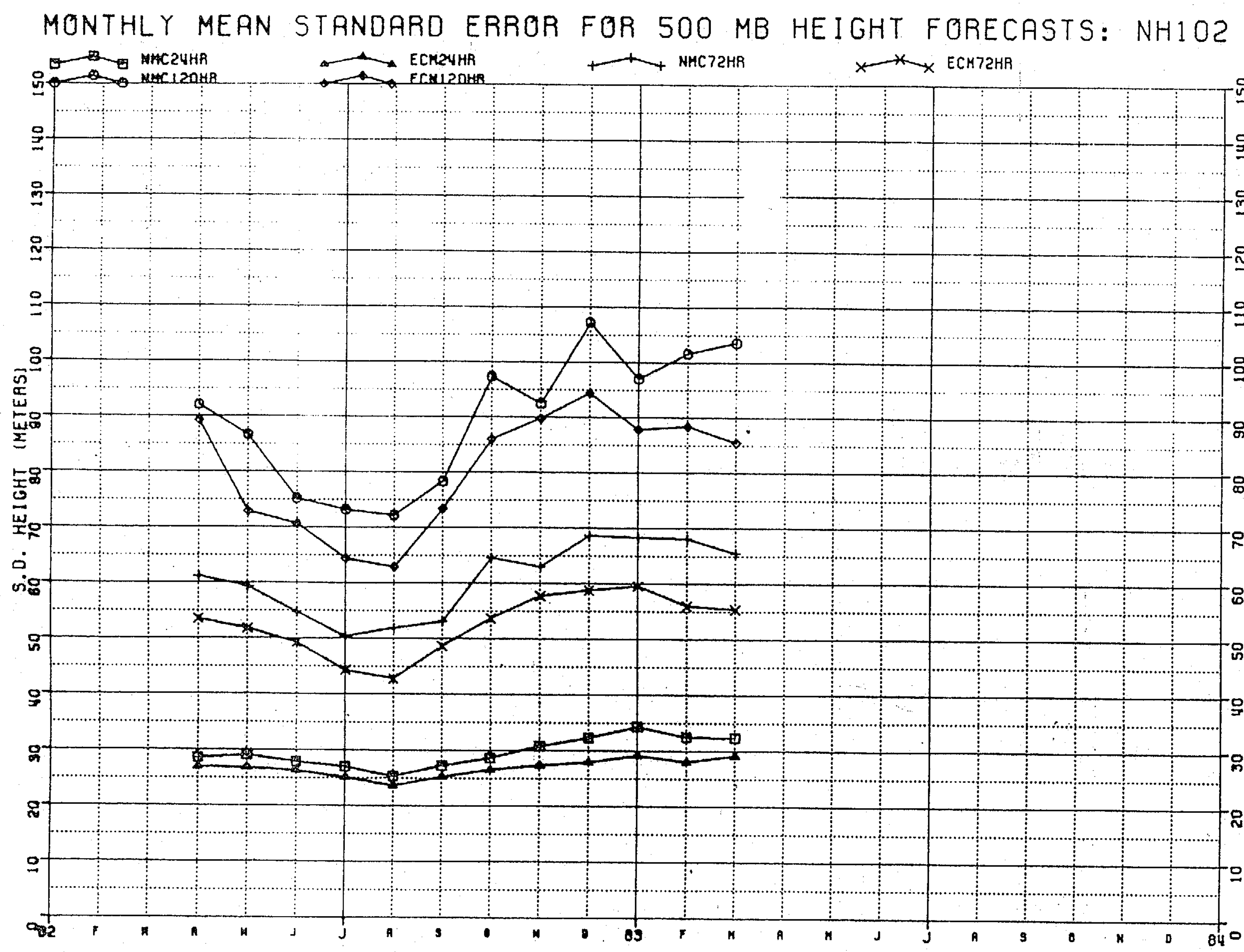
120
132
144
FORECAST HOUR

Figure 6c


MONTHLY MEAN STANDARD ERROR FOR 500 MB HEIGHT FORECASTS: NH102
NMC24HR
NMC120HR
ECM24HR
ECM120HR
NMC72HR
ECM72HR
S.D. HEIGHT (METERS)
0
10
20
30
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60
70
80
90
100
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120
130
140
150
82
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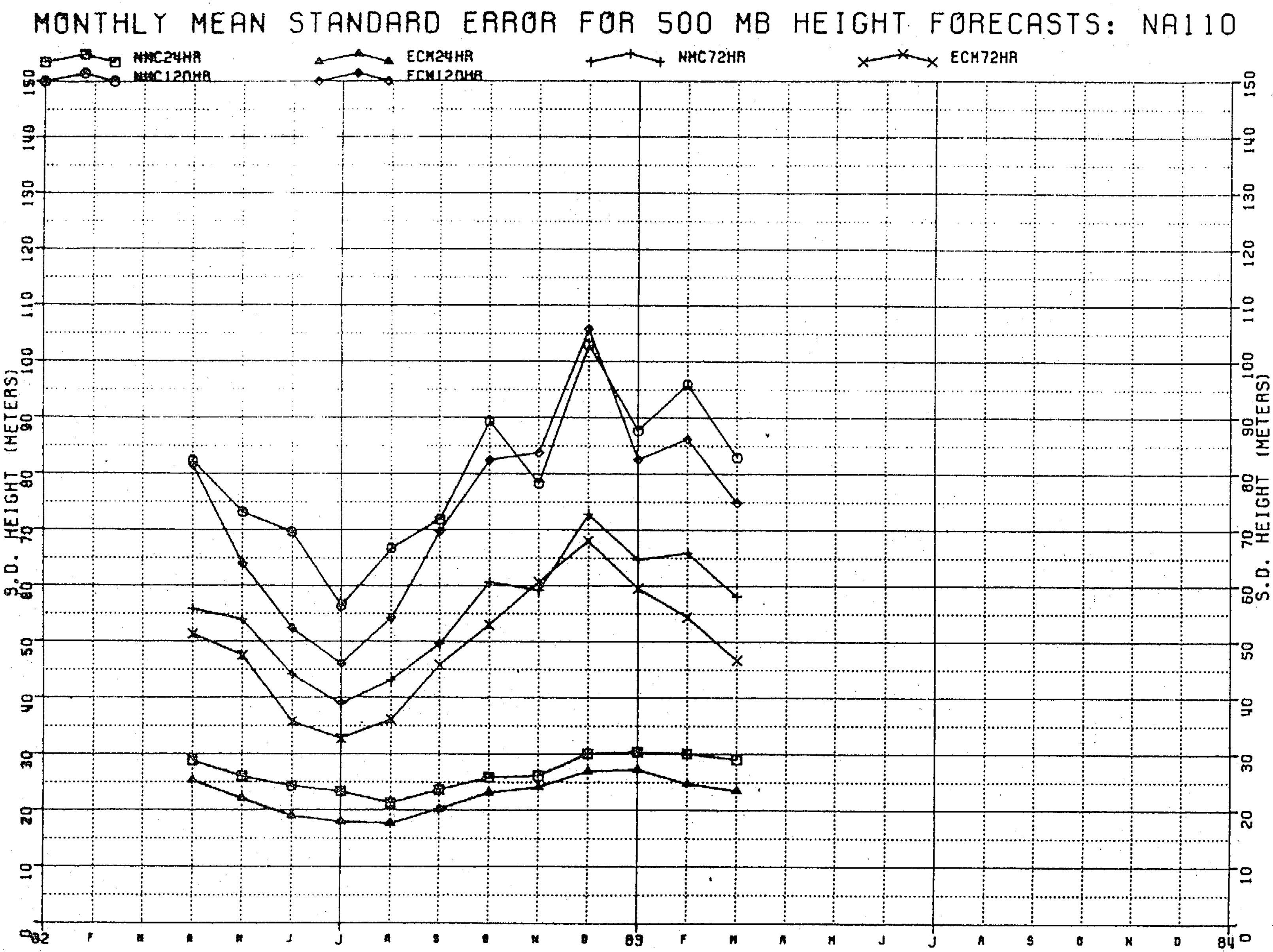
84

Figure 7a


MONTHLY MEAN STANDARD ERROR FOR 500 MB HEIGHT FORECASTS: NA110
NMC24HR
NMC120HR
ECM24HR
ECM120HR
NMC72HR
ECM72HR
S.D. HEIGHT (METERS)
0
10
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30
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100
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120
130
140
150
82
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M
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J
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O
N
D
84

Figure 7b

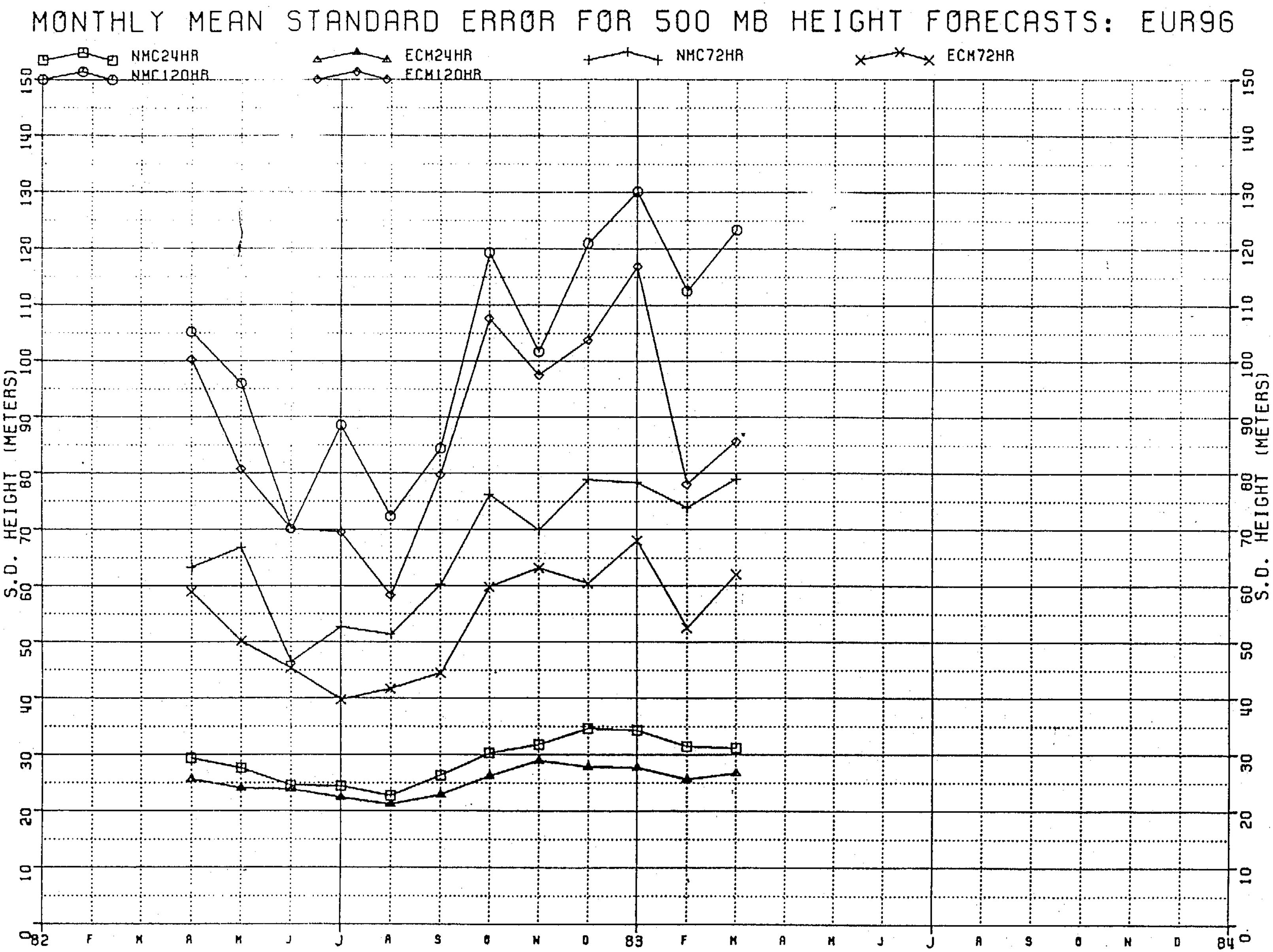
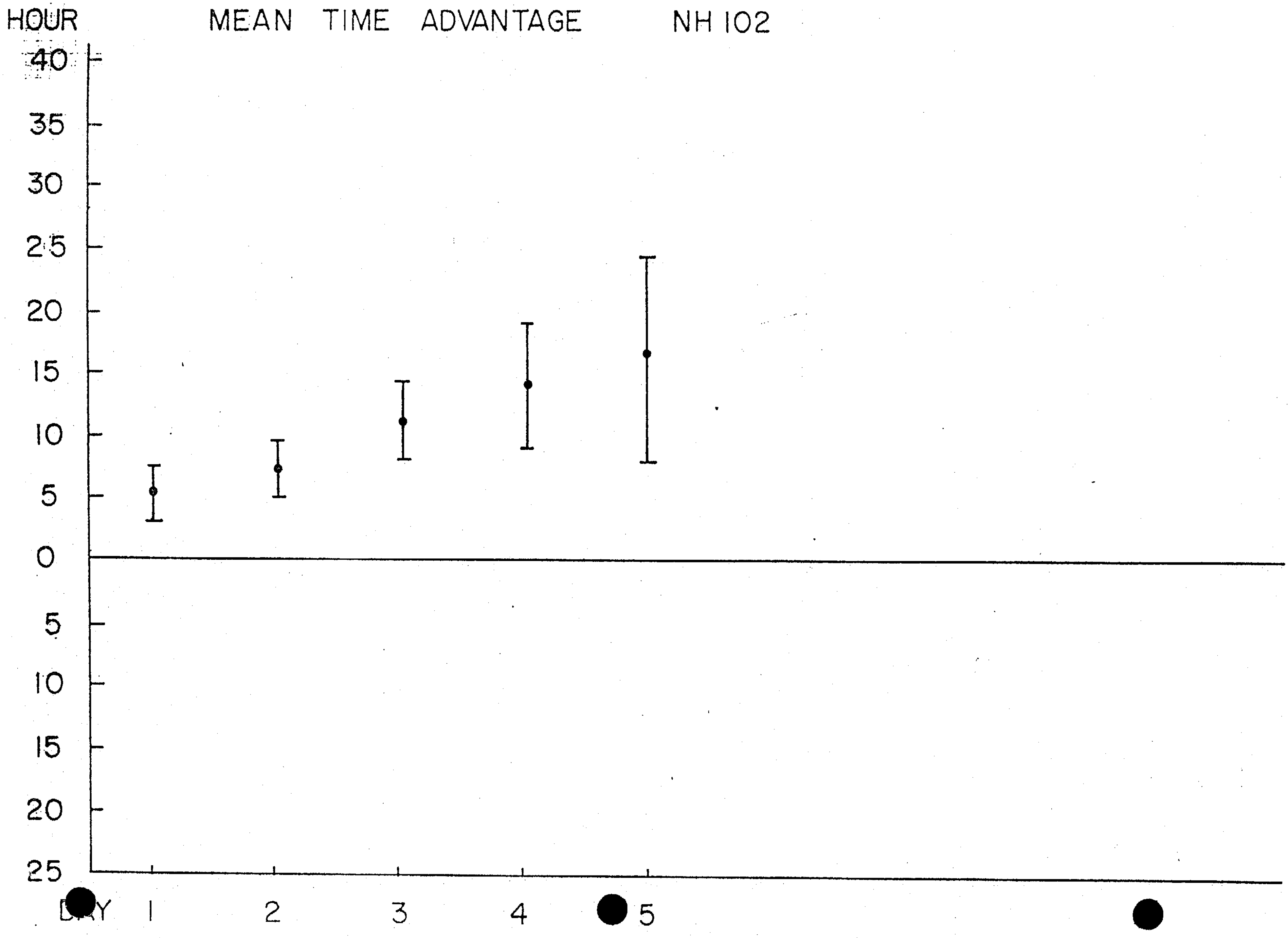
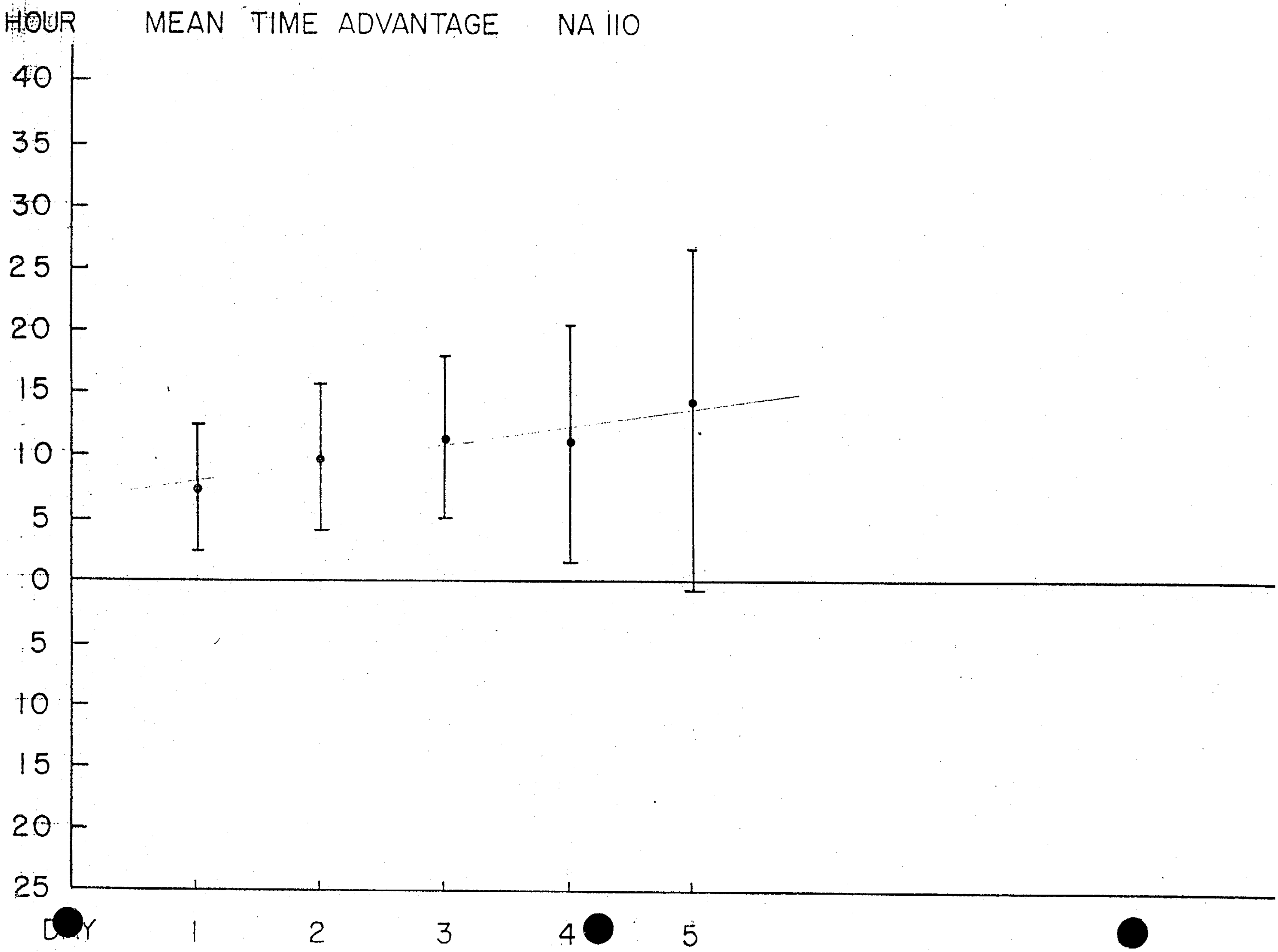
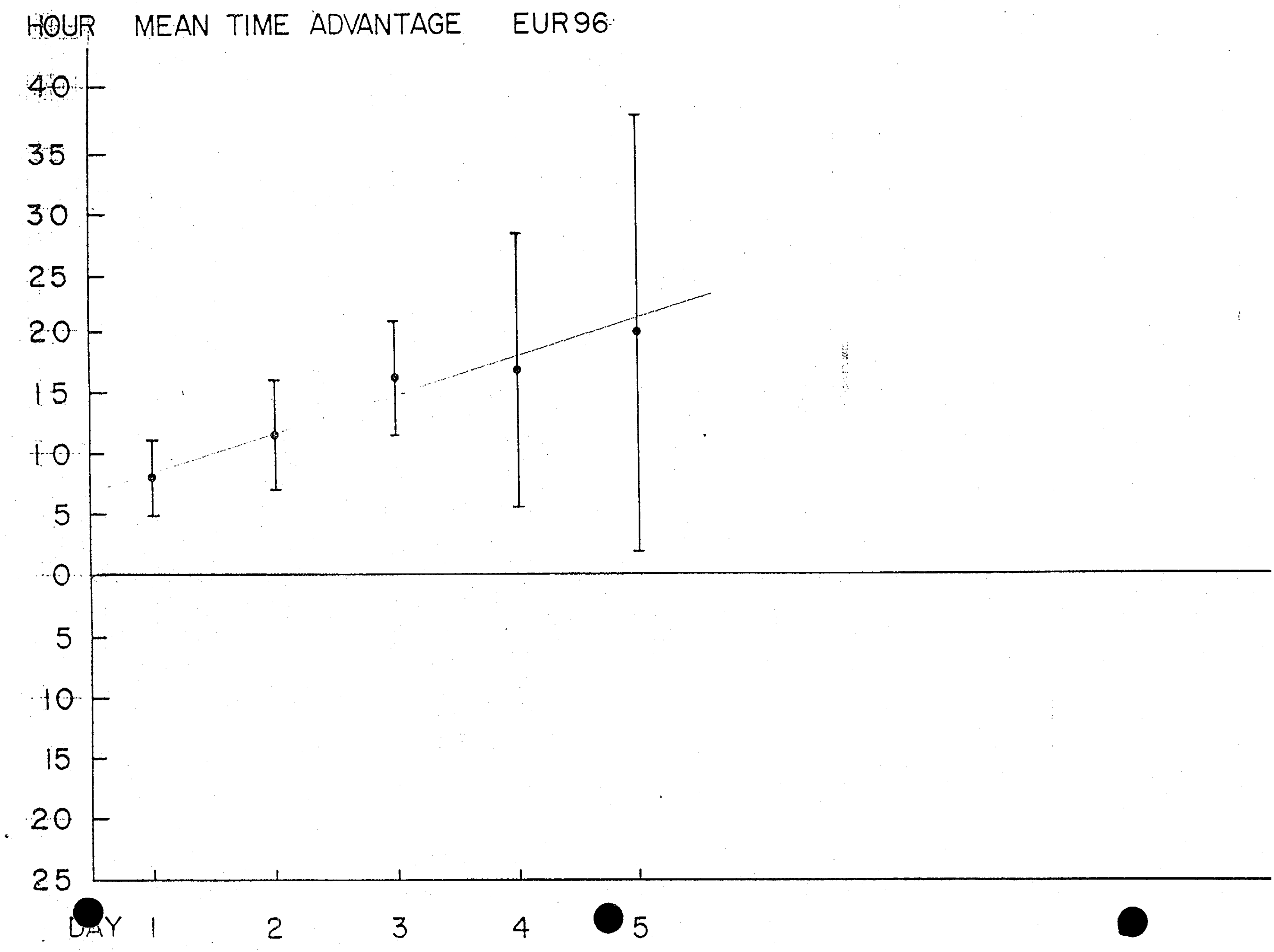

MONTHLY MEAN STANDARD ERROR FOR 500 MB HEIGHT FORECASTS: EUR96
NMC24HR
ECM24HR
NMC72HR
ECM72HR
NMC120HR
ECM120HR
S.D. HEIGHT (METERS)
82 F M A M J J A S O N D 83 F M A M J J A S O N D 84

Figure 7c


HOUR
MEAN TIME ADVANTAGE NH 102
40
35
30
25
20
15
10
5
0
5
10
15
20
25
DAY 1 2 3 4 5


HOUR
MEAN TIME ADVANTAGE NA 110
40
35
30
25
20
15
10
5
0
5
10
15
20
25
DAY
1
2
3
4
5



HOUR
MEAN TIME ADVANTAGE
EUR 96
40
35
30
25
20
15
10
5
0
5
10
15
20
25
DAY
1
2
3
4
5